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Introduction to
Input-Output analysis

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MUSE - Track Energy

Methods for analysing energy efficiency and renewable energy technologies

Contents of the class

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- Theory
  - Basics of macro-economics
  - Input / Output tables (IOT)
  - Input-output analysis (IOA) – Multipliers & impacts
- Examples
  - Total Output calculation
  - Energy consumption change
- Learning outcomes – the exercise
  - Looks into environmental impacts from a macro-economic perspective
  - Trains your ability with spreadsheet calculations
  - Emulates a scientific approach

Theory

How does the economy work?

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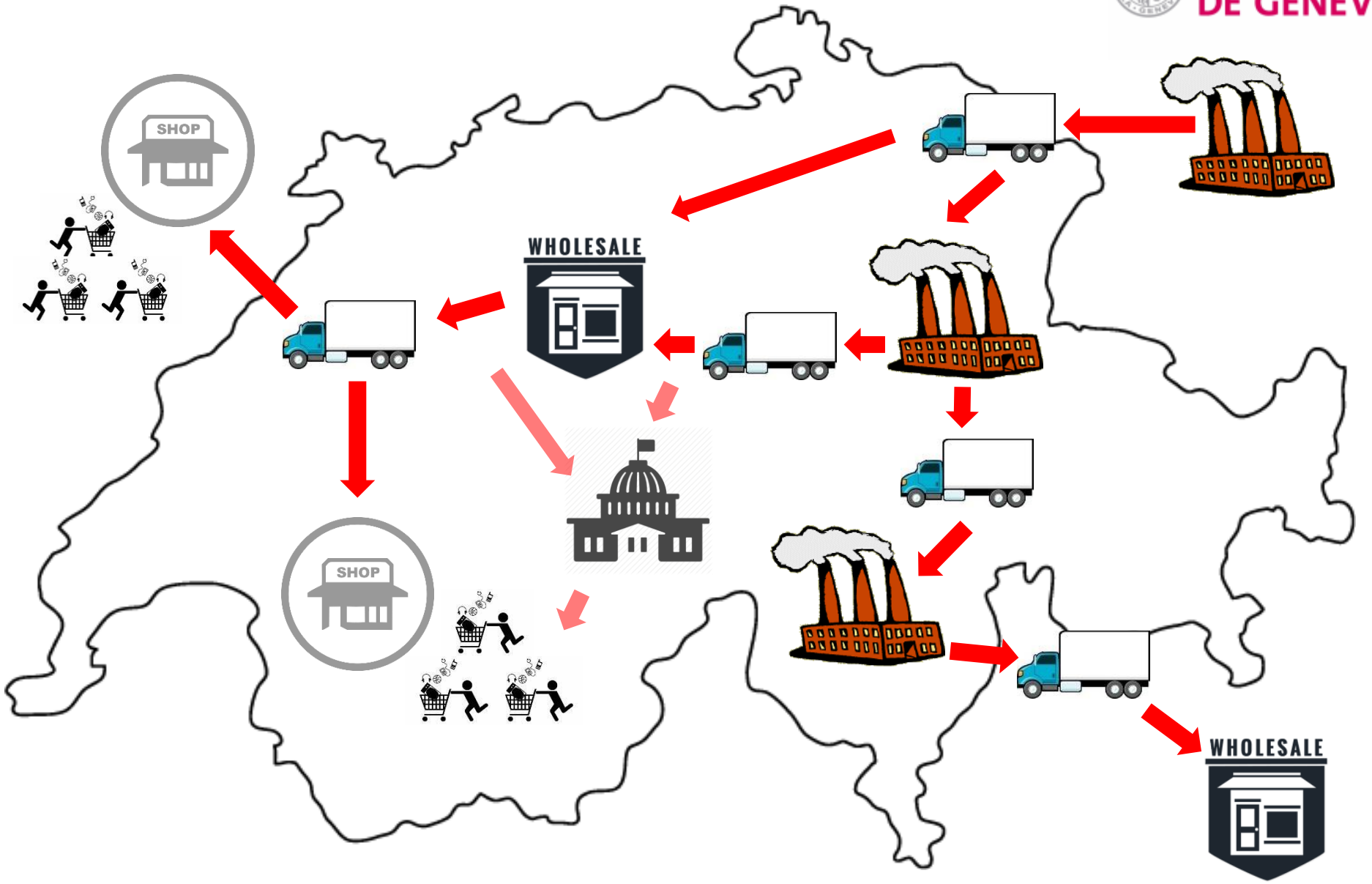
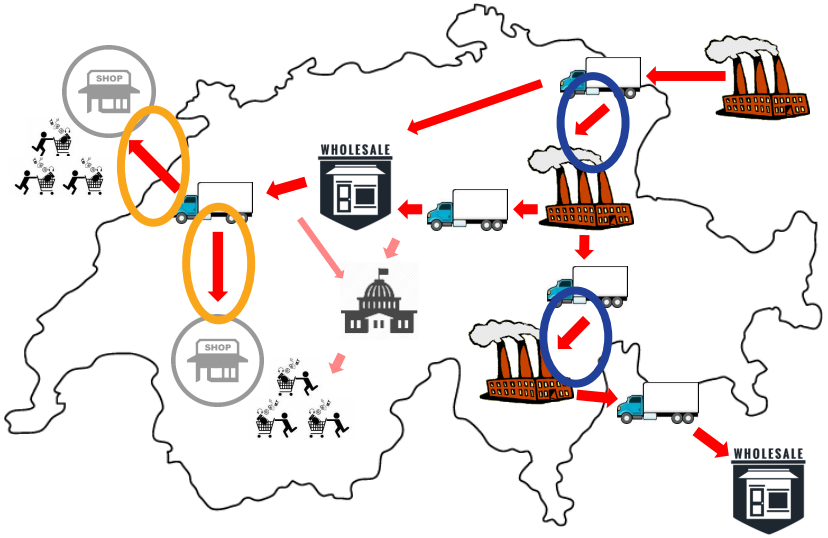


Definitions

- **Final demand** – goods and services consumed by households; government, non-governmental institutions, and social security systems; companies with regard to gross capital formation; and goods and services used for export.

- **Intermediate demand** – goods and services (apart from capital goods) used for production of other goods and services (including imports).

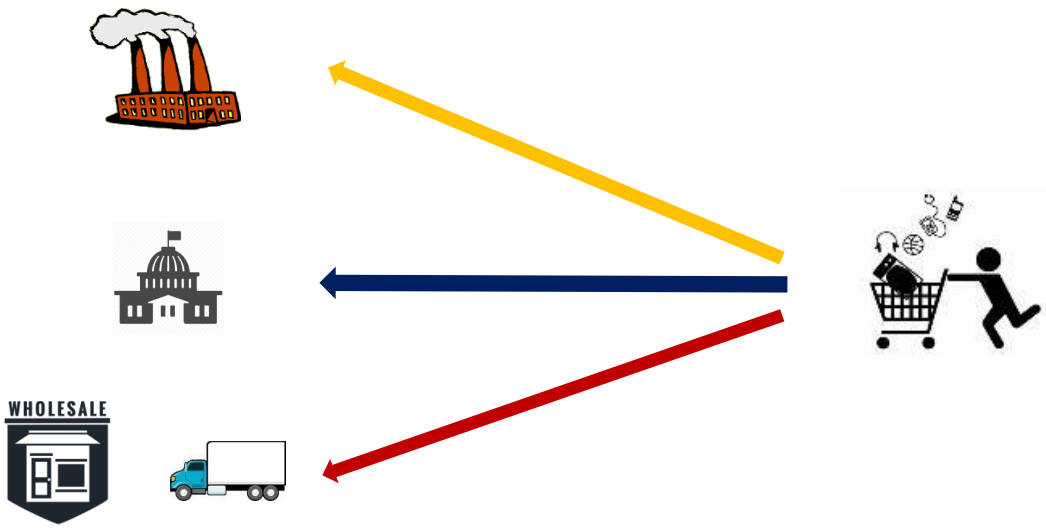
- **Total demand** – Final demand + Intermediate demand



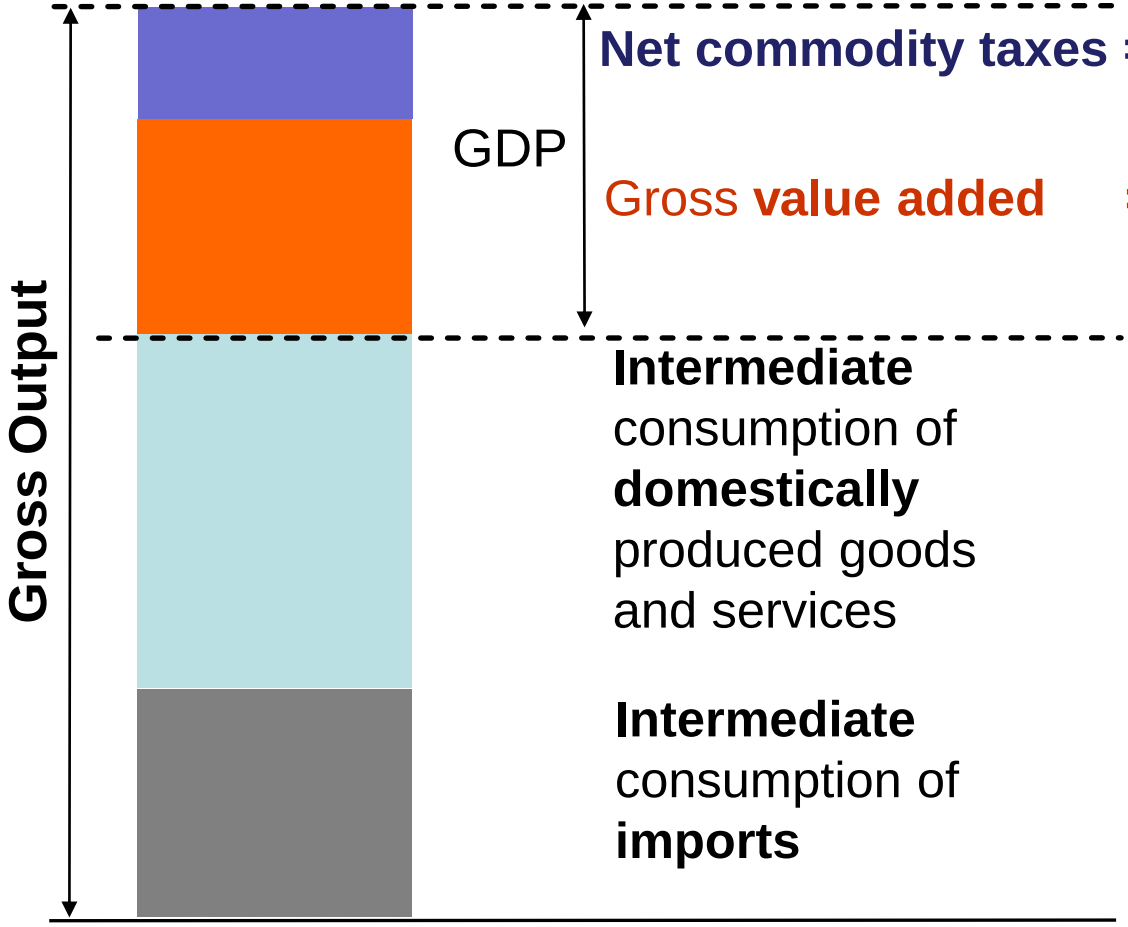
Source: Yushchenko A, Patel M.K., 2016, *Contributing to a green energy economy? A macroeconomic analysis of an energy efficiency program operated by a Swiss utility*, Applied Energy.

More definitions

- **Producer** price = **Basic** price + Net commodity **taxes**
- **Consumer** price = **Producer** price + **Trade** and **transport** margin



Contribution of products to GDP



Balance principle

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For the entire economy:

Gross Output

= Total supply of goods and services

= Total demand for goods and services

= Units · Basic Price

= Intermediate demand + Final demand

= Intermediate demand + Value added

Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

Input-Output Analysis (IOA)

IOA is used to estimate an overall economic activity triggered by a change in final demand (itself triggered by a policy measure, a communication campaign, a consumer choice...):

- **System boundaries: Only** change in final demand of **domestic** goods and services has impact on **local economy**!

Vs.

Image credits: http://laborrightsblog.typepad.com/.a/6a00d8341bf90b53ef0105361df60e970c-pi
https://marriottschool.byu.edu/upload/news/images/975-954-istock_000019501469medium.jpg

Different tiers of impact

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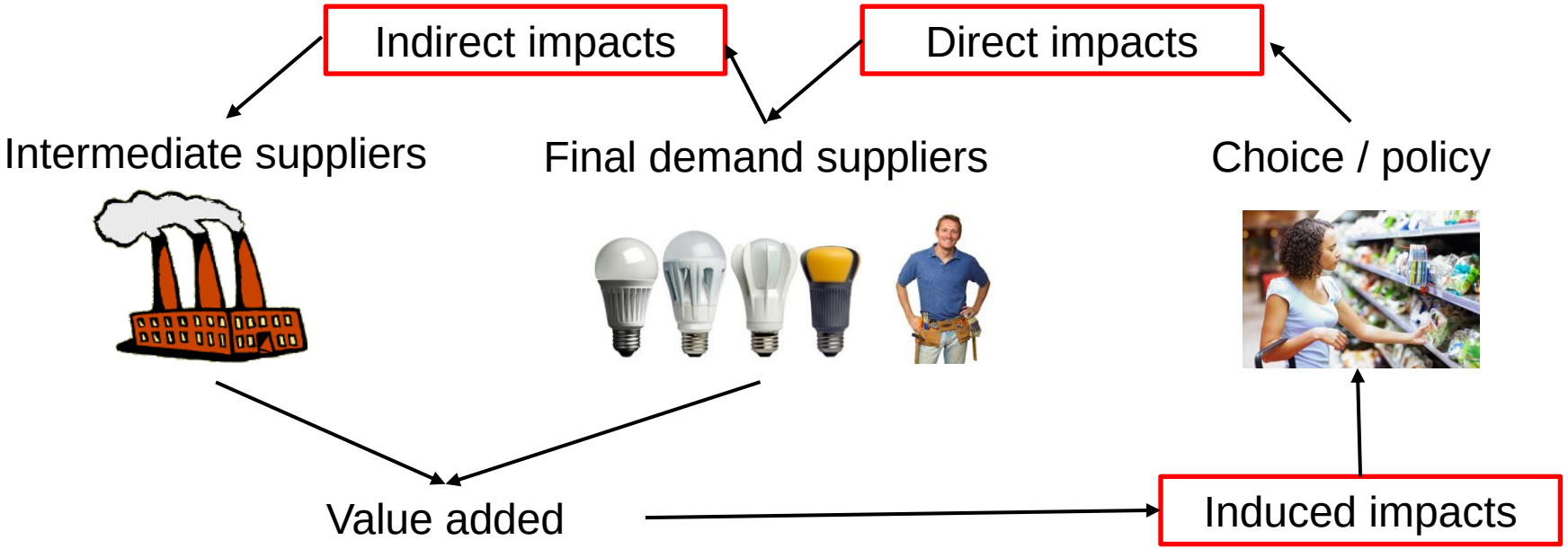
- **Direct impacts** - impacts that take place in economic sectors that supply goods and services for final demand.
- **Indirect impacts** – upstream multiplier effects on economic sectors that supply goods and services for intermediate demand.
- **Induced impacts** – multiplier effects of change in final demand as a result of income change.



Source: Yushchenko A, Patel M.K., 2016, *Contributing to a green energy economy? A macroeconomic analysis of an energy efficiency program operated by a Swiss utility*, Applied Energy.
Images: http://m.nieir.com.au/yourPlace_IO/using_input_output_tables_in_analysis.htm http://www.mediashower.com/img/1204/man%20with%20tool%20belt.jpg https://upload.wikimedia.org/wikipedia/commons/thumb/b/b6/Factory_1b.svg/1245px-Factory_1b.svg.png http://farm8.staticflickr.com/7201/6888463257_6ebb8de48e.jpg

Gross and net impacts

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- **Gross impacts** – overall impacts caused by a measure (without any comparison/correction)

- **Net impacts** - impacts caused by a measure relative to an alternative measure or a reference case

  "net = gross - reference"

Source: Yushchenko A, Patel M.K., 2016, *Contributing to a green energy economy? A macroeconomic analysis of an energy efficiency program operated by a Swiss utility*, Applied Energy.
Image: https://www.englishclub.com/images/vocabulary/cw-gross-vs-net.png

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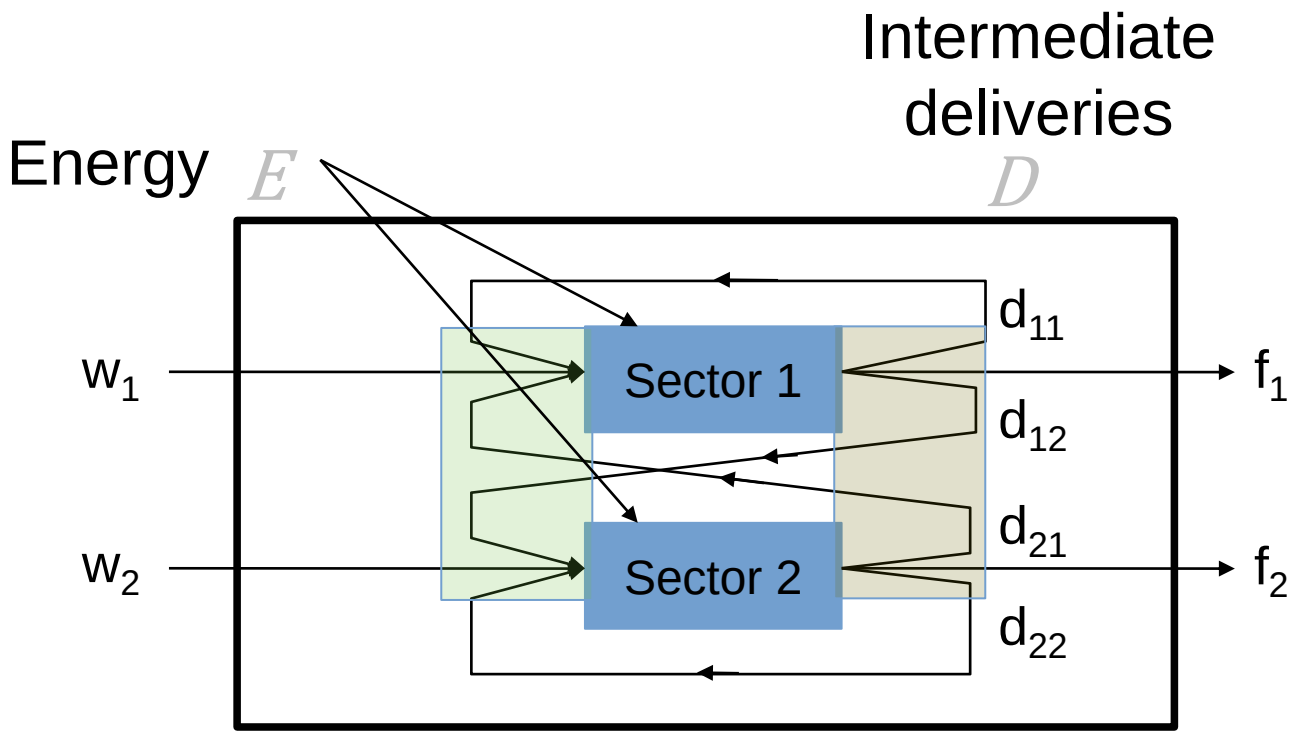
Applications

Simplified economy



General representation of an IOT

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Columns j: Supply to (=input of) receiving sector j

Rows i: Deliveries from (=output of) supplying sector i

All values in MCHF	Basic metal industry	Electro technical industry	Machinery industry
Basic metal industry	d_{11}	d_{12}	d_{13}
Electrotechnical industry	d_{21}	d_{22}	d_{23}
Machinery industry	d_{31}	d_{32}	d_{33}

- d_{ij} – intermediate deliveries from sector i to sector j
- f_i – final demand from (or deliveries of) sector i to end users
- w_j – value added by sector j (= total output – intermediate input)
- x_k – total output (sum horizontally) from sector k
  = total input (sum vertically) to sector k $x_i = \sum_{j=1}^{n} d_{ij} + f_i = \sum_{k=1}^{n} d_{ki} + w_i$

Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

A more elaborated input-output table

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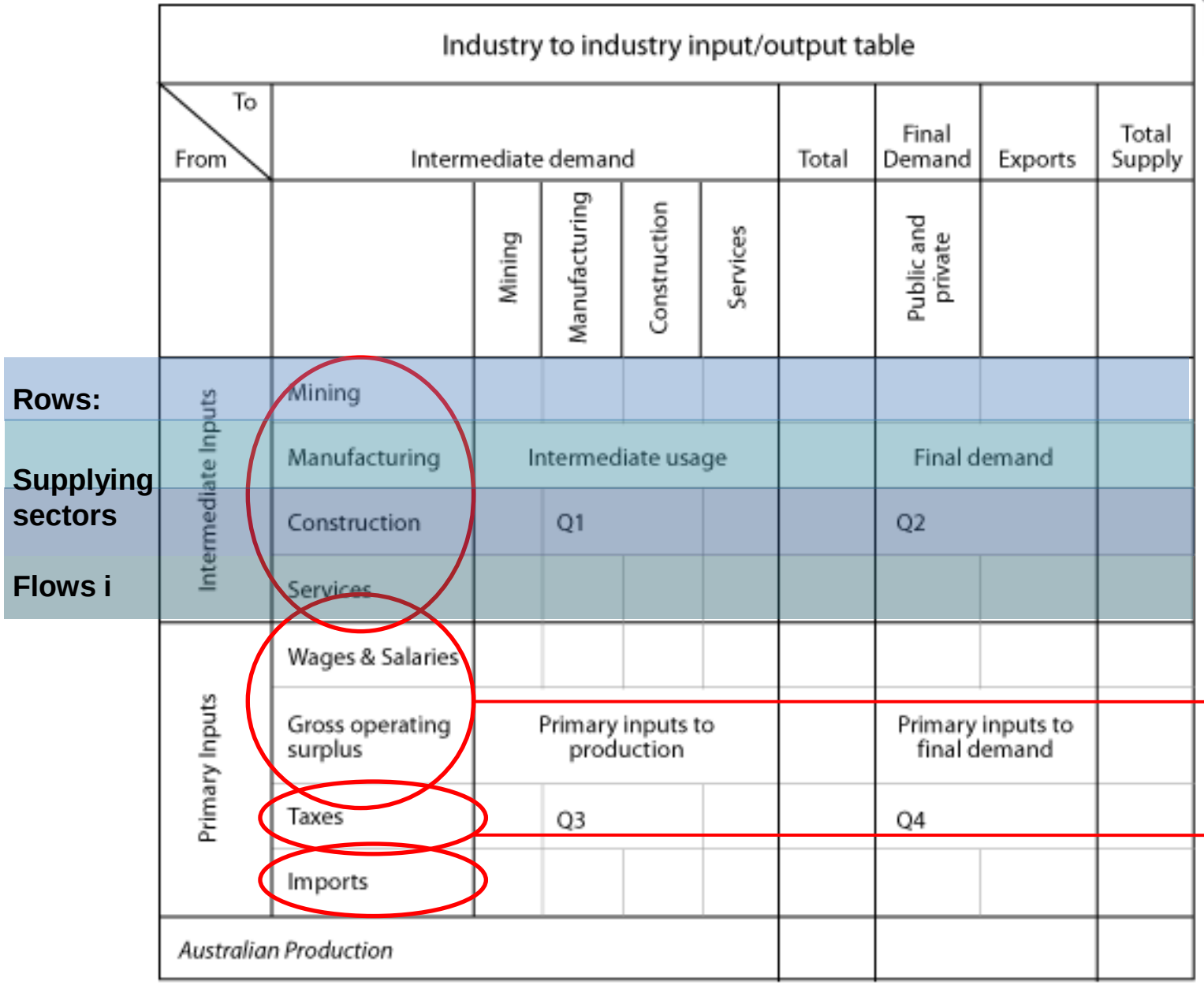

Source: http://m.nieir.com.au/yourPlace_IO/using_input_output_tables_in_analysis.htmv

Columns:
Receiving sectors
Flows j

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Industry to industry input/output table

To / From		Intermediate demand: Mining	Intermediate demand: Manufacturing	Intermediate demand: Construction	Intermediate demand: Services	Total	Final Demand: Public and private	Final Demand: Exports	Total Supply
Intermediate Inputs	Mining								
	Manufacturing	Intermediate usage					Final demand		
	Construction		Q1				Q2		
	Services								
Primary Inputs	Wages & Salaries								
	Gross operating surplus	Primary inputs to production					Primary inputs to final demand		
	Taxes		Q3				Q4		
	Imports								
Australian Production									

Goods and services consumed (no further transformation)

Goods and services used for production of other goods and services (subject to further transformation)

Source: http://m.nieir.com.au/yourPlace_IO/using_input_output_tables_in_analysis.htmv

IOT of a simplified economy, million CHF

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All values in MCHF	Basic metal industry	Electro technical industry	Machinery industry	House-holds (F. demand)	Total output
Basic metal industry	784	217	135	2	1138
Electrotechnical industry	32	737	234	1066	2069
Machinery industry	300	89	160	4271	4820
Added value	22	1026	4291	0	5339
Total input	1138	2069	4820	5339	13366

Int. dem. + Final demand = Int. dem. + Value added

Total input = Total output

Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

Remember: balance principle

For the entire economy:

Gross Output

= Total supply of goods and services

= Total demand for goods and services

= Units · Basic Price

= Intermediate demand + Final demand

= Intermediate demand + Value added

Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

Notes

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- A delivery from sector i to sector j is at the same time :
  - An output **from** i delivered **to** j
    AND
  - An input **to** j supplied **from** i.

When we speak about totals:

- Total output **from** (a single) sector **i** is an *homogeneous* mix of products delivered to different sectors (sum over j, incl. f_j)
- Total input **to** sector **j** is an *heterogeneous* mix of products supplied from different sectors (sum over i, incl. w_i)

- Total output generated in the economy is the sum of total outputs from every sector = sum of total inputs to every sector

Matrix of intermediate deliveries

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All values in MCHF	Basic metal industry	Electro technical industry	Machinery industry	House-holds	Total output
Basic metal industry	784	217	135	2	1138
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Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

Technology matrix A

- Intermediate demand per unit of output = Technology matrix

Matrix of intermediate deliveries

	Basic metal industry	Electro technical industry	Machinery industry	Households	Total
Basic metal industry	784	217	135	2	1138
Electrotechnical industry	32	737	234	1066	2069
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Added value	22	1026	4291	0	5339
Total	1138	2069	4820	5339	13366

$$a_{ij} = \frac{d_{ij}}{x_j}$$

$$A = \begin{bmatrix} 0.689 & 0.105 & 0.028 \\ 0.028 & 0.356 & 0.049 \\ 0.264 & 0.043 & 0.033 \end{bmatrix}$$

Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

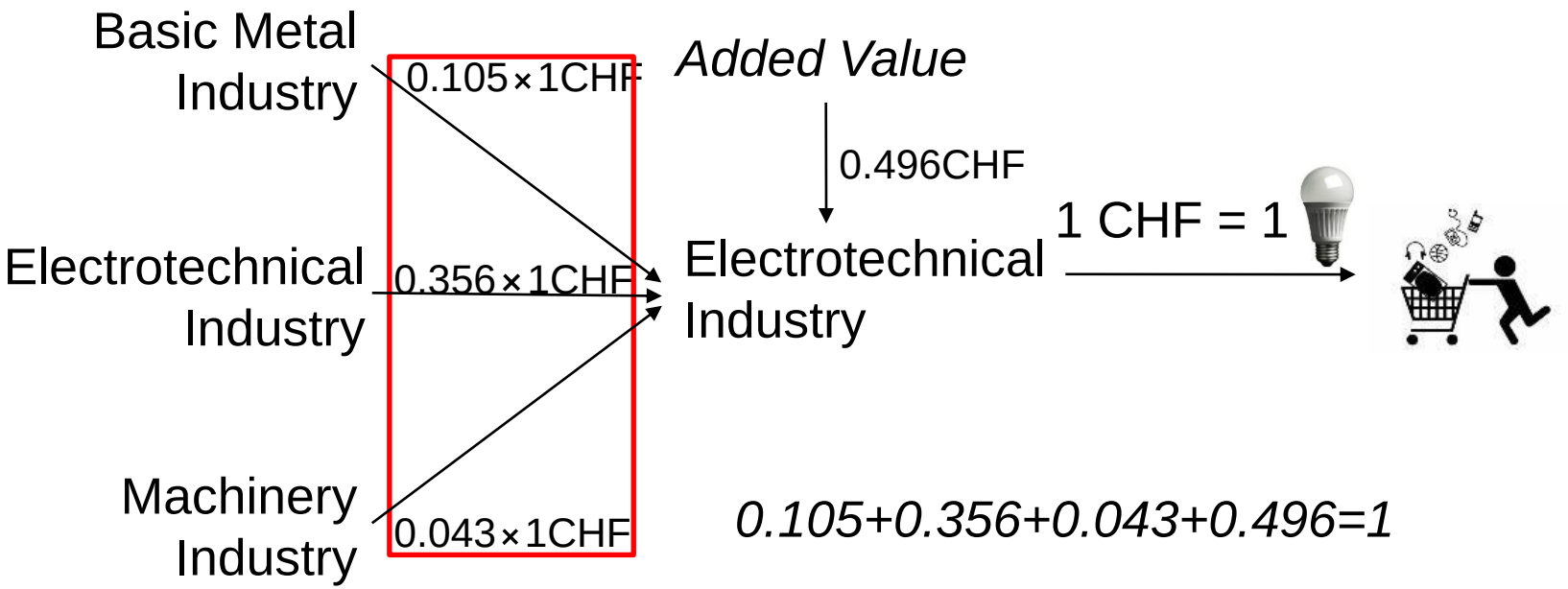
First order deliveries

- Purchases producer j has to make to deliver one unit of product i
- Example: “1 Franc light bulb”

Intermediate demand

$$A * \Delta F = \begin{bmatrix} 0.689 & 0.105 & 0.028 \\ 0.028 & 0.356 & 0.049 \\ 0.264 & 0.043 & 0.033 \end{bmatrix} * \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$

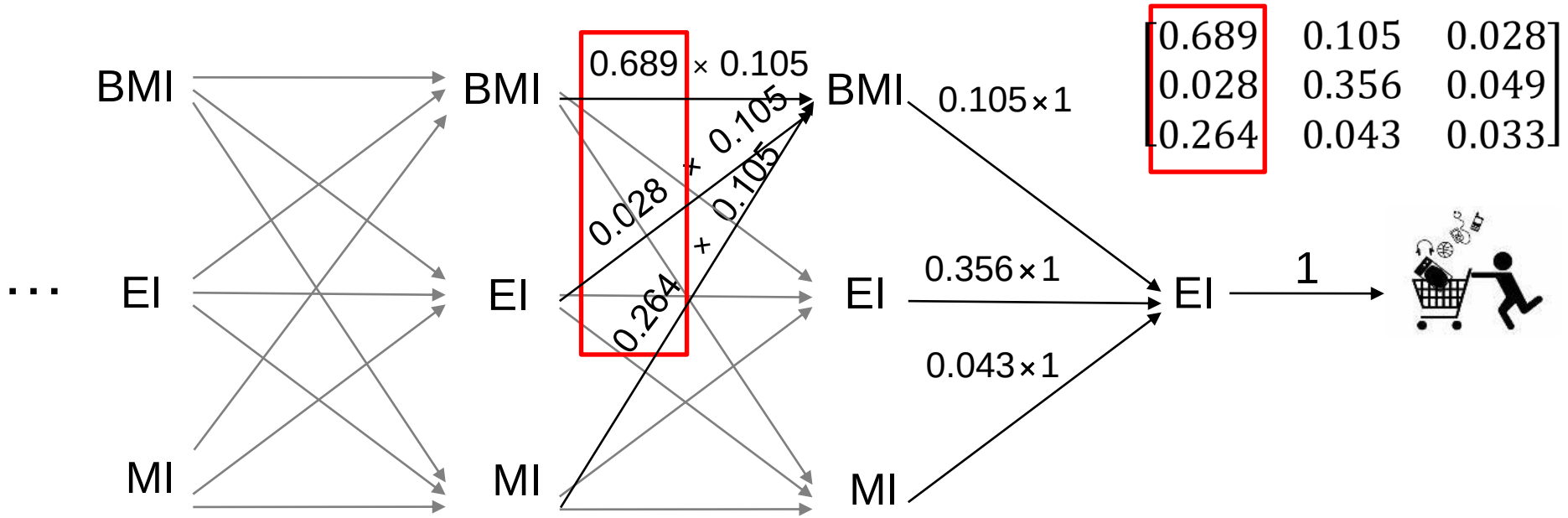
Final demand change



Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

Second, third, … order deliveries

- Second order deliveries $A * A * \Delta F$
- Third order deliveries $A * A * A * \Delta F$
- How to calculate all deliveries needed?



NB: The symbol "∗" is used to denote simple matrix multiplication: $(A*B)_{ij}=a_{ij}\times b_{ji}$. Standard notation uses no symbol. Beware that this operation is not commutative: $A * B \neq B * A$.

Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

Total output (or deliveries)

$$\Delta X = [I + A + A^2 + A^3 \ldots] * \Delta F$$

where $I = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

Result from algebra

$$P = [I + A + A^2 + A^3 \ldots] = (I - A)^{-1}$$

Leontief inverse matrix!

Shows direct + indirect output

$$P = \begin{bmatrix} 3.37 & 0.56 & 0.13 \\ 0.22 & 1.59 & 0.09 \\ 0.93 & 0.22 & 1.07 \end{bmatrix}$$

How much output is generated from sector i as a result of demand for one unit of product of the sector j (here: how much machinery is built to produce 1 MCHF in light bulbs)

Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

Results

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- Total output (or deliveries) for all final demand

$$X = P * F = \begin{bmatrix} 3.37 & 0.56 & 0.13 \\ 0.22 & 1.59 & 0.09 \\ 0.93 & 0.22 & 1.07 \end{bmatrix} * \begin{pmatrix} 2 \\ 1066 \\ 4271 \end{pmatrix} = \begin{bmatrix} 1138 \\ 2069 \\ 4820 \end{bmatrix}$$

	Basic metal industry	Electro technical industry	Machinery industry	Households	Total
Basic metal industry	784	217	135	2	1138
Electrotechnical industry	32	737	234	1066	2069
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Results

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Total output multipliers = Sum of columns of P

How much output is generated in the economy if 1 MCHF of goods are purchased from sector j (here basic metal industry)

4.52 2.37 1.29

×2 ×1066 ×4271

9 2531 5487 → Sum = 8027

Most of the output in this economy is due to demand for Machinery.

Other types of analysis

- IOT can be combined with other statistical data (on GDP, employment, energy consumption, emissions…)
- Allows to estimate overall environmental and socio-economic impacts
- Sectoral classification should be identical (not always achieved in practice)

	Table 1. STATEM			
T2.8a	**Emplois en équivalents plein temps**			
	par divisions économiques			
	Total			
	Valeurs trimestrielles, en milliers			
		Branches économiques		Av
Sections et divisions				2011
		IOT code		
B-S	5-96	2011	Total	3 419.3
B-F	5-43		SECTEUR II	972.2
B	**5-9**	**05-09**	**Industries extractives**	**4.2**
C	**10-33**		**Industrie manufacturière**	**628.7**
	10-12	10-12	Industries alimentaires et du tabac	59.8
	13-15	13-15	Industries du textile et de l'habillement	14.7
	16-18	Divided into 16, 17, 18	Industries du bois et du papier ; imprimerie	68.3
	19-20	19-20	Cokéfaction, raffinage et industrie chimique	28.6
	21	21	Industrie pharmaceutique	36.6
	22-23	Divided into 22, 23	Industries du caoutchouc et du plastique	39.5
	24-25	Divided into 24, 25	Fabrication de produits métalliques	95.3
	26	26	Fabrication de produits électroniques; horlog	102.4
	27	27	Fabrication d'équipements électriques	36.1
	28	28	Fabrication de machines et équipements n.c.	82.0
	29-30	Divided into 29, 30	Fabrication de matériels de transport	14.9
	31-33	Divided into 31, 32, 33	Autres industries manufacturières; rép. et inst.	50.5
D	**35**	**35**	**Production et distribution d'énergie**	**24.7**
E	**36-39**	**36-39**	**Production et distr. d'eau; gestion des déch**	**13.7**
F	**41-43**	**41-43**	**Construction**	**300.9**
	41-42		Construction de bâtiments et génie civil	103.2
	43		Travaux de construction spécialisés	197.8

Source: http://www.bfs.admin.ch/bfs/portal/fr/index/infothek/erhebungen__quellen/blank/blank/statistique_de_l_emploi/00.html

Example: energy-extended I/O analysis

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- Combine IOT [million CHF] and energy consumption data [TJ]

	Total Output [MCHF]	Energy consumption [TJ]	Energy intensity [TJ/MCHF]
Basic metal industry	1138	25	0.0220
Electrotechnical industry	2069	4	0.0019
Machinery industry	4820	6	0.0012
Added value	5339	-	-
Total	13366	35	-

E

Energy consumed to produce 1MCHF of total output from j

Option 1: Energy Intensity

$$\Delta E = E \circ \Delta X$$

Example:

$$\underbrace{0.022}_{E} \times \underbrace{\begin{bmatrix}1138\\2069\\4820\end{bmatrix}}_{\Delta X} = \underbrace{\begin{bmatrix}25\\4\\6\end{bmatrix}}_{\Delta E}$$

=35 TJ

Energy [TJ] consumed by machinery industry to supply 4820MCHF of goods.

Energy intensity vector: How much energy is consumed by sector i to produce 1MCHF of goods.

NB: ”○“ is simply an element by element product

Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

Option 2: Energy multiplier matrix

$$\Delta X = P * \Delta F \Rightarrow \Delta E = (E \circ P) * \Delta F$$

1) Computation:

$$\underbrace{\begin{matrix}0.022 \times \\ 0.002 \times \\ 0.001 \times\end{matrix}}_{E}\underbrace{\begin{bmatrix}3.37 & 0.56 & 0.13\\ 0.22 & 1.59 & 0.09\\ 0.93 & 0.22 & 1.07\end{bmatrix}}_{P} = \underbrace{\begin{bmatrix}0.0741 & 0.0123 & 0.0028\\ 0.0004 & 0.0031 & 0.0002\\ 0.0012 & 0.0003 & 0.0013\end{bmatrix}}_{E \circ P}$$

Output from sector i as a result of demand from sector j

Energy consumed by sector i for 1MCHF of output

2) Illustration:

$$\underbrace{\begin{bmatrix}0.0741 & 0.0123 & 0.0028\\ 0.0004 & 0.0031 & 0.0002\\ 0.0012 & 0.0003 & 0.0013\end{bmatrix}}_{E \circ P} * \underbrace{\begin{bmatrix}2\\ 1066\\ 4271\end{bmatrix}}_{\Delta F} = \underbrace{\begin{bmatrix}25\\ 4\\ 6\end{bmatrix}}_{\Delta E}$$

Energy multiplier matrix: Energy consumed by sector i (Mach. Ind.) as a result of demand from sector j (El. Ind.)

Total energy consumed by the Mach. Ind. given a vector of final demand change

Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

Option 3: Energy multipliers

= Total energy consumption generated by final demand from one sector:

$$\Delta E = (E \circ P) * \Delta F = \begin{bmatrix} 0.0741 & 0.0123 & 0.0028 \\ 0.0004 & 0.0031 & 0.0002 \\ 0.0012 & 0.0003 & 0.0013 \end{bmatrix} * \begin{bmatrix} 2 \\ 1066 \\ 4271 \end{bmatrix} = \begin{bmatrix} 25 \\ 4 \\ 6 \end{bmatrix}$$

Energy multipliers = Sum of columns of $E \circ P$

Energy multiplier vector: How much energy is consumed across the economy if 1MCHF of goods are purchased from sector j (here Metal Ind.).

0.0756 0.0156 0.0043

× 2 × 1066 × 4271

0.2 16.6 18.4

Sum = 35 TJ

Demand for electronic products generates a proportionately large share of energy consumption

Option 3 bis: Energy multipliers

Energy multipliers can be directly computed from the energy intensity vector as:

1) E^T P

$$E * P = [0.022 \quad 0.002 \quad 0.001] * \begin{bmatrix} 3.37 & 0.56 & 0.13 \\ 0.22 & 1.59 & 0.09 \\ 0.93 & 0.22 & 1.07 \end{bmatrix}$$

$$= [0.0756 \quad 0.0156 \quad 0.0043]$$

$\times 2$ $\times 1066$ $\times 4271$

2) $0.2 \quad 16.6 \quad 18.4 \longrightarrow$ Sum $= 35$ TJ

Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

Energy-extended I/O analysis – summary

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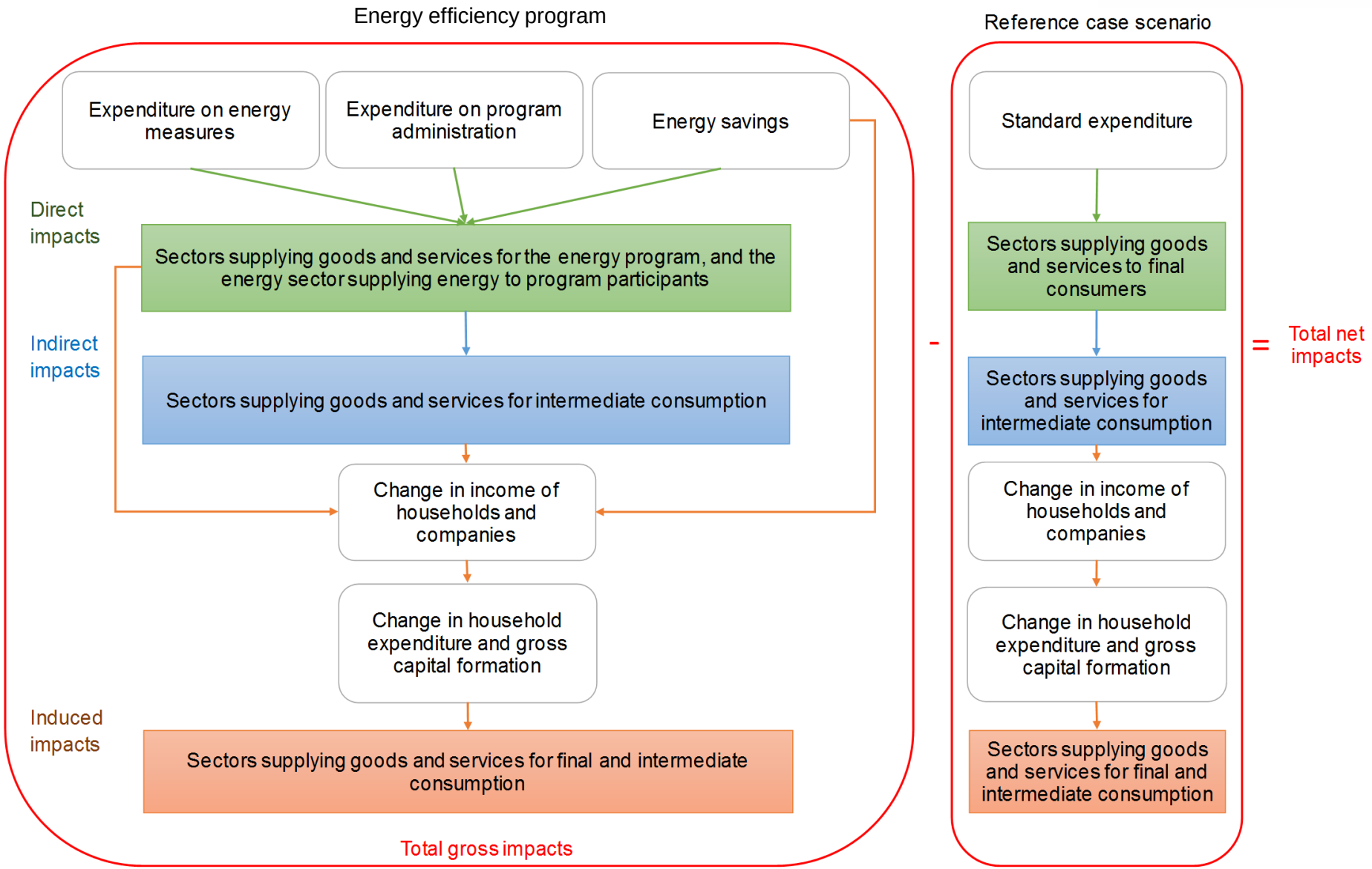
- **Option 1:** Energy intensity: Multiply by *output* of a sector to obtain the energy consumption *of that sector*
- **Option 2:** Energy multiplier matrix: multiply by *final demand from* a sector to obtain energy consumption *of each other sector* to supply that demand.
- **Option 3:** Energy multiplier vector: Multiply by *final demand from* a sector to obtain energy consumption *across the economy* due to that demand.
- Energy multipliers represent change in energy consumption of all sectors caused by a change in final consumption from a sector j
- Change in energy consumption = Multiplier * Change in final demand

Source: K. Blok and E. Nieuwlaar, *Introduction to Energy Analysis*, Routledge editors, 2020

Gross and net impacts – Example



Source: Yushchenko A, Patel M.K., 2016, *Contributing to a green energy economy? A macroeconomic analysis of an energy efficiency program operated by a Swiss utility*, Applied Energy.

Wrap-up

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- Input-output tables represent the relationships between economic sectors regarding production, import, and consumption of goods and services.
- IO analysis is used to evaluate impacts across the economy (direct, indirect, and induced) and compare alternatives (gross vs. net impacts).
- IO analysis is more comprehensive, but less detailed compared to other types of analysis (i.e., process analysis).
- IO analysis can be combined with other types of analyses. In practice, combination of input-output tables with other statistical data may be difficult (for example, due to differences in sectoral classification).

Source: Yushchenko A, Patel M.K., 2016, *Contributing to a green energy economy? A macroeconomic analysis of an energy efficiency program operated by a Swiss utility*, Applied Energy.

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Thank you for your attention

Questions?